

EPA 520/1-6-83-007

POTENTIAL HEALTH AND ENVIRONMENTAL
HAZARDS OF URANIUM MINE WASTES

A Report to the Congress of the United States
in Response to Public Law 95-604

Volume 2 of 3 Volumes

June 10, 1983

U.S. Environmental Protection Agency
Office of Radiation Programs
Washington, D.C. 20460

	Page
1.4.2 State Regulations	1-42
1.4.2.1 Colorado	1-45
1.4.2.2 New Mexico	1-47
1.4.2.3 Texas	1-49
1.4.2.4 Utah	1-49
1.4.2.5 Washington	1-50
1.4.2.6 Wyoming	1-51
1.5 References	1-53
2.0 Inventory of Uranium Mines	2-1
2.1 References	2-16
3.0 Potential Sources of Contaminants to the Environment and Man	3-1
3.1 Background Concentrations of Radionuclides and Trace Metals	3-1
3.1.1 Naturally Occurring Radionuclides	3-1
3.1.2 Stable Elements	3-6
3.2 Water-Related Aspects of Uranium Mining	3-11
3.2.1 Previous and Ongoing Hydrologic and Water Quality Studies Related to Uranium Mining	3-11
3.2.2 Mine Water Management	3-13
3.2.3 Water Quality Effects of Mine Water Discharge	3-23
3.2.3.1 Behavior of Contaminants in the Aqueous Environment	3-23
3.2.3.1.1 Dilution and Suspended Sediment Transport	3-25
3.2.3.1.2 Sorption and Desorption	3-25
3.2.3.1.3 Precipitation	3-28
3.2.3.1.4 Biological Assimilation and Degradation	3-30
3.2.3.1.5 Complexation	3-31
3.2.3.2 Results of Field Studies in Uranium Mining Areas	3-32

	Page
3.2.3.2.1 Colorado	3-32
3.2.3.2.2 Wyoming	3-34
3.2.3.2.3 Texas	3-38
3.2.3.2.4 New Mexico	3-39
3.2.3.3 Summary	3-43
3.3 Surface Mining	3-44
3.3.1 Solid Wastes	3-44
3.3.1.1 Overburden Piles	3-45
3.3.1.2 Ore Stockpiles	3-54
3.3.1.3 Sub-Ore Piles	3-60
3.3.1.4 Reclamation of Overburden Piles	3-62
3.3.2 Mine Water Discharge	3-63
3.3.2.1 Data Sources	3-63
3.3.2.2 Quantity and Quality of Discharge	3-64
3.3.3 Hydraulic and Water Quality Effects of Surface Mine Discharge	3-68
3.3.3.1 Runoff and Flooding in the Model Surface Mine Area	3-68
3.3.3.1.1 Study Approach	3-68
3.3.3.1.2 Description of Area	3-70
3.3.3.1.3 Method of Study	3-72
3.3.3.1.4 Discussion of Results	3-77
3.3.3.2 Impacts of Seepage on Groundwater	3-89
3.3.4 Gases and Dusts from Mining Activities	3-93
3.3.4.1 Dusts and Fumes	3-93
3.3.4.2 Radon-222 from the Pit, Storage Piles, and Ore Handling	3-99
3.4 Underground Mining	3-107
3.4.1 Solid Wastes	3-107
3.4.1.1 Waste Rock Piles	3-109
3.4.1.2 Ore Stockpiles	3-110
3.4.1.3 Sub-Ore Piles	3-112

	Page
3.4.2 Mine Water Discharge	3-113
3.4.2.1 Data Sources	3-113
3.4.2.2 Quality and Quantity of Discharge	3-114
3.4.3 Hydraulic and Water Quality Effects of Underground Mine Discharge	3-120
3.4.3.1 Runoff and Flooding in the Model Underground Mine Area	3-120
3.4.3.1.1 Study Approach	3-120
3.4.3.1.2 Description of Area	3-122
3.4.3.1.3 Estimate of Sub-basin Flood Flow	3-124
3.4.3.1.4 Prediction of Sub-basin Water Quality	3-132
3.4.3.2 Impacts of Seepage on Groundwater	3-149
3.4.4 Gases and Dusts from Mining Activities	3-155
3.4.4.1 Radon-222 in Mine Exhaust Air	3-155
3.4.4.2 Aboveground Radon-222 Sources	3-157
3.4.4.3 Dusts and Fumes	3-159
3.5 In Situ Leach Mining	3-168
3.5.1 Solid Wastes	3-169
3.5.2 Associated Wastewater	3-172
3.5.3 Airborne Emissions	3-174
3.5.4 Excursion of Lixiviant	3-178
3.5.5 Restoration and Reclamation	3-179
3.6 Other Sources	3-185
3.6.1 Mineral Exploration	3-185
3.6.1.1 Environmental Considerations	3-187
3.6.1.2 Radon Losses from Drill Holes	3-192
3.6.1.3 Groundwater	3-193
3.6.1.4 Fumes	3-193
3.6.1.5 Model Drilling	3-194
3.6.2 Precipitation Runoff from Uranium Mines	3-194
3.7 Inactive Mines	3-204
3.7.1 Inactive Surface Mines	3-204
3.7.1.1 Waste Rock Piles	3-213

	Page
3.7.1.2 Radon-222 from the Mine Area	3-216
3.7.1.3 Land Surface Gamma Radiation	3-222
3.7.2 Inactive Underground Mines	3-227
3.7.2.1 Waste Rock Piles	3-229
3.7.2.2 Radon-222 from the Mine Area	3-232
3.7.2.3 Land Surface Gamma Radiation	3-237
3.8 References	3-242
4.0 Description of Model Mines	4-1
4.1 Surface Mine	4-1
4.2 Underground Mine	4-4
4.3 In Situ Leach Mine	4-7
4.4 Inactive Surface Mine	4-8
4.5 Inactive Underground Mine	4-9
5.0 Potential Pathways	5-1
5.1 General	5-1
5.1.1 Vegetation	5-1
5.1.2 Wildlife	5-1
5.1.3 Land Use	5-2
5.1.4 Population Near Mining Areas	5-2
5.1.5 Population Statistics of Humans and Beef Cattle	5-12
5.2 Prominent Environmental Pathways and Parameters for Aqueous Releases	5-12
5.2.1 Individual Committed Dose Equivalent Assessment	5-13
5.2.2 Collective (Population) Dose Equivalent Assessment	5-15
5.3 Prominent Environmental Pathways and Parameters for Atmospheric Releases	5-16
5.3.1 Individual Committed Dose Equivalent Assessment	5-16
5.3.2 Collective (Population) Dose Equivalent Assessment	5-18
5.4 Mine Wastes Used in the Construction of Habitable Structures	5-19
5.5 References	5-20
6.0 Health and Environmental Effects	6-1
6.1 Health Effects and Radiation Dosimetry	6-1

	Page
6.1.1 Radioactive Airborne Emissions	6-1
6.1.2 Nonradioactive Airborne Emissions	6-26
6.1.2.1 Combustion Products	6-26
6.1.2.2 Nonradioactive Gases	6-28
6.1.2.3 Trace Metals and Particulates in the Form of Dust	6-28
6.1.3 Radioactive Aquatic Emissions	6-35
6.1.4 Nonradioactive Aquatic Emissions	6-42
6.1.5 Solid Wastes	6-44
6.1.5.1 Radium-226 Content	6-44
6.1.5.2 Estimates of Potential Risk	6-45
6.1.5.3 Using Radium Bearing Wastes in the Construction of Habitable Structures	6-46
6.1.5.3.1 Use of Uranium Mine Wastes	6-48
6.2 Environmental Effects	6-48
6.2.1 General Considerations	6-48
6.2.2 Effects of Mine Dewatering	6-52
6.2.3 Erosion of Mined Lands and Associated Wastes	6-54
6.2.4 Land Disturbance from Exploratory and Development Drilling	6-56
6.2.5 Land Disturbance from Mining	6-59
6.2.5.1 Underground Mines	6-59
6.2.5.2 Surface Mines	6-59
6.2.6 Retirement Phase	6-59
6.3 References	6-73
7.0 Summary and Recommendations	7-1
7.1 Overview	7-1
7.2 Sources and Concentrations of Contaminants	7-1
7.2.1 Surface and Underground Mines	7-1
7.2.2 In Situ Leach Mines	7-7
7.2.3 Uranium Exploration	7-8
7.3 Exposure Pathways	7-8
7.4 Potential Health Effects	7-9

	Page
7.4.1 Radioactive Airborne Emissions	7-9
7.4.2 Nonradioactive Airborne Emissions	7-13
7.4.3 Radioactive Aqueous Emissions	7-13
7.4.4 Nonradioactive Aqueous Emissions	7-15
7.4.5 Solid Wastes	7-16
7.5 Environmental Impacts	7-16
7.5.1 Land and Water Contamination	7-17
7.5.2 Effects of Mine Dewatering	7-22
7.5.3 Erosion of Mined Lands and Associated Wastes	7-22
7.5.4 Exploratory and Development Drilling	7-23
7.5.5 Underground Mining	7-23
7.5.6 Surface Mining	7-24
7.6 Regulatory Perspective	7-25
7.7 Conclusions and Recommendations	7-25
7.7.1 Conclusions	7-26
7.7.1.1 Solid Wastes	7-26
7.7.1.2 Airborne Effluents	7-26
7.7.1.3 Waterborne Effluents	7-27
7.7.1.4 Exploratory and Development Drilling	7-27
7.7.2 Recommendations to Congress	7-28
7.8 Other Findings	7-28
7.9 References	7-29

Appendixes (See Volume 3)

- A. Summary of Federal Laws Potentially Affecting Uranium Mining
- B. Federal Water Programs and Rights Activities
- C. Congressionally Approved Compacts that Apportion Water
- D. State Laws, Regulations, and Guides for Uranium Mining
- E. Active Uranium Mines in the United States
- F. Inactive Uranium Mines in the United States
- G. General Observations of Uranium Mine Sites in Colorado,
New Mexico, Texas, and Wyoming.

- H. Influence of Mine Drainage on Seepage to Groundwater and Surface Water Outflow
- I. Computation of Mass Emission Factors for Wind Erosion
- J. Aquatic Dosimetry and Health Effects Models and Parameter Values
- K. Airborne Pathway Modeling
- L. Health Risk Assessment Methodology

FIGURES

	Page
1.1 Uranium mining regions in the western United States	1-4
1.2 The percent of \$50 U ₃ O ₈ reserves located in the principal mining states	1-8
1.3 The percent of \$50 U ₃ O ₈ reserves located in the various mining regions	1-9
1.4 Artist's conception of open pit mining operation and support facilities	1-13
1.5 Generalized underground mine showing modified room and pillar method of mining	1-17
1.6 Diagrams of some common injection-recovery well patterns used in uranium in situ leach mining	1-26
2.1 Location of active and inactive uranium mines and principal uranium mining districts in Colorado	2-6
2.2 Location of active and inactive uranium mines and principal uranium mining districts in the Uravan Mineral Belt of western Colorado	2-7
2.3 Location of active and inactive uranium mines in the Grants Mineral Belt and other areas of New Mexico	2-8
2.4 Location of active, inactive, and proposed surface and in situ uranium mines in Texas	2-9
2.5 Location of uranium mines and mining districts in Utah	2-10
2.6 Location of uranium mines and principal uranium mining districts in southeastern Utah	2-11
2.7 Location of active and inactive uranium mines and principal uranium mining areas in Wyoming	2-12
2.8 Location of active and inactive uranium mines in the Gas Hills and Crooks Gap-Green Mountain areas of central Wyoming	2-13
2.9 Location of active and inactive uranium mines in the Shirley Basin, South Powder River Basin, and Pumpkin Buttes areas of Wyoming	2-14

	Page
3.1 The uranium decay series showing the half lives and mode of decay	3-2
3.2 The thorium decay series showing the half lives and mode of decay	3-3
3.3 Disposition of drainage water from active surface and underground uranium mines	3-14
3.4 Location of mines, ore and waste storage areas and monitoring stations at the Morton Ranch mine, South Powder River Basin, Wyoming	3-37
3.5 Location of study areas, sampling stations and uranium mines, Poison Canyon area, McKinley County, New Mexico	3-41
3.6 Sample locations for radionuclides and select trace metals in sediments, San Mateo mine, New Mexico	3-42
3.7 Potential sources of environmental contamination from active open pit uranium mines	3-46
3.8 Storage pile configurations assumed at surface and underground mines	3-48
3.9 Sketch of sub-basin, basin, and regional basin showing orientation of principal drainage courses, areas of drainage, and location of mines	3-69
3.10 Average monthly flows for the Cheyenne River and Lance Creek near Spencer, Wyoming, for the period 1948-1970	3-71
3.11 Suspended sediment concentration to discharge, Salt Wells Creek and Tributaries, Wyoming	3-75
3.12 Relation of discharge and specific conductance to time at Salt Wells Creek, Green River Basin, Wyoming	3-76
3.13 Periods of no flow in Lance Creek and the Cheyenne River near Riverton, Wyoming, for the period 1948-1978. . . .	3-82
3.14 Configuration of open pit model mines	3-105
3.15 Potential sources of environmental contamination from active underground uranium mines	3-108

3.16 Sketch of sub-basin, basin, and regional basin showing orientation of principal drainage courses, areas of drainage, and location of mines in the New Mexico model area	3-121
3.17 Average monthly flows for the period of record for the Rio San Jose and the Rio Puerco in New Mexico	3-129
3.18 Periods of no flow in the Rio San Jose and Rio Puerco	3-131
3.19 Total flow volumes in one-day periods for floods of various recurrence intervals in the sub-basin and basins in New Mexico	3-133
3.20 Total flow volumes in seven-day periods for floods of various recurrence intervals in the sub-basin and basins in New Mexico	3-134
3.21 Principal streams and surface water sampling stations in the Churchrock and Gallup areas	3-145
3.22 Average depth of exploratory drilling in the U.S. uranium industry from 1948 to present	3-188
3.23 Annual waste to ore ratios for surface mining of uranium (1948 to 1979)	3-209
3.24 Cross section of model inactive surface mine	3-214
3.25 Results of gamma exposure rate survey at the 1601 pit and environs, Morton Ranch uranium mine, Converse County, Wyoming	3-226
3.26 Waste to ore ratios for inactive underground uranium mines from 1932 to 1977	3-228
3.27 Radon-222 concentrations in mine air discharged by natural ventilation	3-236
3.28 Gamma radiation survey around an inactive underground uranium mine in New Mexico	3-240
5.1 Potential airborne pathways in the vicinity of uranium mines	5-17

6.1	Average indoor radon-222 decay product measurements (in working levels) as a function of average radium-226 concentration in soil	6-47
6.2	Example of natural reclamation of drill sites	6-57
6.3	Inactive underground mine site	6-60
6.4	Example of active and inactive surface mining activities	6-63
6.5	Mine wastes eroded by ephemeral streams in the Mesa Montanosa area, New Mexico	6-64
6.6	Basal erosion of a uranium mine waste pile by an ephemeral stream in the Mesa Montanosa area, New Mexico	6-65
6.7	Scattered piles of mine waste at the Mesa Top mine, Mesa Montanosa, New Mexico	6-66
6.8	Close-up view of easily eroded sandy and silty mine waste from the Mesa Top mine, Mesa Montanosa, New Mexico	6-66
6.9	Gullying and sheet erosion of piled and spread mine wastes at the Dog Incline uranium mine, Mesa Montanosa, New Mexico	6-67
6.10	Recent erosion of unstabilized overburden piles at the inactive Galen mine, Karnes County, Texas	6-68
6.11	Unstabilized overburden piles and surface-water erosion at the Galen mine, Karnes County, Texas	6-68
6.12	Aerial view of the Manka mine, Karnes County, Texas	6-70
6.13	Overburden pile showing the weak vegetative cover and gullying associated with improper stabilization at the Manka mine, Karnes County, Texas,	6-70
6.14	Inactive Hackney mine, Karnes County, Texas	6-72

Appendix G

G.1	Plan view of inactive underground uranium mine No. 1, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado	G-3
-----	---	-----

G.2	Sectional view of inactive underground uranium mine No. 2, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado	G-4
G.3	Plan view of inactive underground uranium mine No. 3, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado	G-6
G.4	Sectional view of inactive underground uranium mine No. 4, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado	G-7
G.5	Plan view of inactive underground uranium mine No. 5, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado	G-8
G.6	Plan view of inactive underground uranium mine No. 6, related waste rock piles, and surface gamma exposure rates, Uravan Mineral Belt, Colorado	G-9
G.7	Plan view of inactive underground uranium mine No. 7, related waste rock piles, and surface gamma exposure rates, Central City District, Colorado	G-11
G.8	Plan view of inactive underground uranium mine No. 8, related waste rock piles, and surface gamma exposure rates, Central City District, Colorado	G-12
G.9	Plan view of inactive underground fluorspar uranium mine No. 9, related waste rock piles, and surface gamma exposure rates, near Jamestown, Colorado	G-13
G.10	Plan view of inactive underground uranium mine No. 10, related waste rock piles, and surface gamma exposure rates, Central City District, Colorado	G-15
G.11	Typical mine waste pile associated with a small- to medium-sized inactive underground uranium mine, Uravan Mineral Belt, Colorado	G-16
G.12	Side view of a typical underground uranium mine located on the rim of a sandstone mesa, Uravan Mineral Belt, Colorado	G-16

	Page
G.13 Mine waste accumulations near the portal of a typical underground rim-type uranium mine, western Colorado	G-17
G.14 Mine waste dump associated with a typical rim-type underground uranium mine, western Colorado	G-17
G.15 Movement of fluorspar-uranium mine wastes from a tailings pile into a stream, Jamestown area, Colorado	G-19
G.16 1972 aerial photograph of the Galen and Pawelek open pit mines, Karnes County, Texas	G-27
G.17 1978 aerial photograph of the Galen and Pawelek open pit mines, Karnes County, Texas	G-27
G.18 Results of gamma exposure rate survey at the 1601 pit and environs, Morton Ranch uranium mine, Converse County, Wyoming	G-31
G.19 Location of sampling stations at the Morton Ranch mine, South Powder River Basin, Wyoming	G-33
G.20 Sample locations for radionuclides and select trace metals in sediments, San Mateo mine, New Mexico	G-34

Appendix H

H.1 Wyoming model area sub-basin drainage system	H-3
H.2 Model area stream cross section	H-3
H.3 New Mexico model area sub-basin drainage system	H-9

Appendix J

J.1 Surface stream flow pattern within drainage area	J-3
J.2 Conservation of mass relationship for resuspension model	J-13

TABLES

		Page
1.1	Domestic uranium production by state from 1948 to January 1, 1979	1-3
1.2	Projected annual nuclear capacity (GWe) in the U.S.	1-6
1.3	Domestic uranium reserves by state as of January 1, 1979	1-7
1.4	The quantities of U_3O_8 produced in 1978 by the various mining methods	1-10
1.5	The predicted methods of mining ore reserves	1-10
1.6	Summary of current in situ leaching operations as of January 1, 1978:	1-21
1.7	Trace metal concentrations of recirculated acid and alkaline lixivants	1-25
1.8	Federal laws, regulations, and guides for uranium mining	1-32
1.9	Requirements to obtain rights to prospect on explore by federal, state and private lands	1-37
1.10	Requirements to obtain rights to mine ore by federal, state and private lands	1-39
1.11	Requirements for mining and environmental plans by federal, state and private lands	1-41
1.12	State laws, regulations, and guides for uranium mining	1-43
2.1	Type of U.S. uranium properties	2-3
2.2	The location and type of active uranium properties	2-4
2.3	The location and type of inactive uranium properties	2-5
2.4	Cumulative ore production through January 1, 1979	2-15
3.1	Gamma-ray energy released by one gram of rock	3-4
3.2	Radionuclide content and dose equivalent rates from common rocks and soil	3-4
3.3	Average dose equivalent rates due to terrestrial radiation in western mining states	3-5
3.4	Radionuclide concentrations in surface and groundwater in the vicinity of a proposed uranium project	3-7
3.5	Concentrations of selected elements in igneous and sedimentary rocks	3-8

	Page
3.6	Concentrations of selected elements in surface water at five locations in the vicinity of a proposed uranium project 3-9
3.7	Concentrations of selected elements in groundwater at six locations in the vicinity of a proposed uranium project. 3-10
3.8	Estimated average concentrations of three metals in U.S. streams 3-6
3.9	Summary of feed water sources for active U.S. uranium mills 3-17
3.10	Current and projected uranium mine discharges in the Grants Mineral Belt, New Mexico 3-21
3.11	Estimated surface areas associated with overburden piles 3-50
3.12	Particle size distributions of mill tailings and mine overburden 3-52
3.13	Natural radionuclide concentrations in various common rock types 3-52
3.14	Annual average airborne radionuclide concentrations in the vicinity of an open pit uranium mine 3-53
3.15	Uranium and stable element concentrations measured in rock and soil samples from two uranium mines 3-55
3.16	Concentration of radionuclides and stable elements in overburden rock from the model surface mines 3-56
3.17	Estimated average areas of ore pile surface and pad . 3-57
3.18	Distribution of ore reserves by the type of host . . 3-59
3.19	Average stable element concentrations in sandstone ores of New Mexico 3-59
3.20	Estimated average surface areas of sub-ore piles during the 17-year active mining period 3-61
3.21	Summary of average discharge and water quality data for uranium mines in Wyoming and a comparison with NPDES limits 3-65
3.22	Water quality associated with surface and underground mines in various stages of construction and operation . 3-67

	Page
3.23 Peak discharge and total volume for floods of 2, 5, 10, 25, 50 and 100 year recurrence intervals	3-78
3.24 Summary of calculated total flow in the Wyoming model area sub-basin using the USGS and SCS methods	3-79
3.25 Annual contaminant loading from one uranium mine and resulting concentrations in floods within the sub-basin for return periods of 2 to 100 years	3-84
3.26 Concentrations in basin and regional basin streams as a result of surface mine discharge	3-86
3.27 Comparison of potable and irrigation water standards and surface water quality affected by surface mine drainage	3-87
3.28 Northeastern Wyoming groundwater sources	3-91
3.29 Groundwater quality of wells sampled by the three major uranium producers in the South Powder River Basin, Wyoming	3-92
3.30 Estimated air pollutant emissions from heavy-duty equipment at surface mines	3-94
3.31 Average annual dust emissions from mining activities	3-97
3.32 Average annual emissions of radionuclides (μ Ci) and stable elements (kg) from vehicular dust at the model surface mines	3-100
3.33 Average annual emissions of radionuclides (μ Ci) and stable elements (kg) from mining activities at the model surface mines	3-101
3.34 Average annual emissions of radionuclides (μ Ci) and stable elements (kg) in wind suspended dust at the model surface mines	3-102
3.35 Radon-222 releases during surface mining	3-107
3.36 Estimated average surface areas of waste rock piles at underground mines	3-111
3.37 Estimated surface areas of ore stockpiles at underground mines	3-111
3.38 Estimated average surface areas of sub-ore piles at underground mines	3-113

3.39	Summary of average discharge and water quality data for underground uranium mines in the Colorado Plateau Region (Colorado, New Mexico, Utah) and a comparison with NPDES limits	3-116
3.40	Water quality associated with underground mines in various stages of construction and operation	3-119
3.41	Total flow volume for sub-basin floods of 1- and 7-day durations and return periods of 2, 5, 10, and 25 years	3-126
3.42	Summary of area, discharge, and irrigated acreage for the sub-basin, basin, and regional basin hydrographic units in New Mexico	3-127
3.43	Dilution factors for the Rio San Jose, Rio Puerco, and Rio Grande for 1-day flood flows with a 2-year recurrence interval	3-135
3.44	Annual contaminant loading from 14 uranium mines and resulting concentrations in sub-basin floods and in the average annual flow of the Rio San Jose, Rio Puerco, and Rio Grande	3-137
3.45	Comparison of potable and irrigation water standards and surface water quality affected by underground mine drainage.	3-140
3.46	Radiochemical and stable element/compound water quality for selected acid and alkaline leach uranium mill tailings ponds in the United States	3-142
3.47	Summary of flood runoff water quality and uranium millpond quality	3-143
3.48	Flow and water quality in the Puerco River near Churchrock and Gallup, New Mexico	3-146
3.49	Groundwater quality in principal aquifers in the Grants Mineral Belt, New Mexico	3-151
3.50	Groundwater quality associated with the San Mateo Creek and Rio Puerco (west) drainages in the Grants Mineral Belt, New Mexico	3-154

3.51	Estimated annual radon-222 emissions from underground uranium mining sources	3-158
3.52	Estimated air pollutant emissions from heavy-duty equipment at underground uranium mines	3-161
3.53	Estimated average annual dust emissions from underground mining activities	3-163
3.54	Average annual emissions of radionuclides (μ Ci) and stable elements (kg) from mining activities at the model underground mines.	3-165
3.55	Average annual emissions of radionuclides (μ Ci) and stable elements (kg) in wind suspended dust at the model underground mines	3-166
3.56	Average annual emissions of radionuclides (μ Ci) and stable elements (kg) from vehicular dust at the model underground mines.	3-167
3.57	Estimated quantities of wastewater produced by an in situ leaching operation	3-173
3.58	Estimated average concentrations and annual accumulation of some contaminants in waste water	3-175
3.59	Estimated average annual airborne emissions from the hypothetical in situ leaching facility	3-176
3.60	Estimated average concentrations and annual and total accumulations of some contaminants in restoration wastewater	3-181
3.61	A comparison of contaminant concentrations in pre-mining groundwater and pre-restoration mine water	3-182
3.62	Estimates of exploratory and development drill holes (1948-1979)	3-189
3.63	Estimated source terms per bore hole for contemporary surface drilling for uranium	3-195
3.64	Airborne dusts produced at an average mine site from exploratory and development drilling	3-196

	Page
3.65 Estimates of emissions from drill rig diesel power source	3-196
3.66 Sediment yields in overland flow from uranium mining areas	3-202
3.67 Consolidated list of inactive uranium producers by State and type of mining	3-206
3.68 Uranium mine waste and ore production	3-207
3.69 Cumulative uranium mine waste and ore production	3-211
3.70 Average annual emissions of radionuclides (μ Ci) and stable elements (kg) in wind suspended dust at the model inactive surface mine	3-217
3.71 Average radon flux of inactive uranium mill tailings piles	3-218
3.72 Average radon flux measured at inactive uranium mine sites	3-220
3.73 Background radon flux estimates	3-221
3.74 Summary of estimated radon-222 releases from inactive surface mines	3-223
3.75 Summary of land surface gamma radiation surveys in New Mexico, Texas, and Wyoming	3-225
3.76 Average annual emissions of radionuclides (μ Ci) and stable elements (kg) in wind suspended dust at the model inactive underground mine	3-231
3.77 Summary of radon-222 releases from inactive underground mines	3-238
3.78 Summary of land surface gamma radiation surveys in Colorado and New Mexico	3-239
5.1 Number of uranium mines and population statistics for counties containing uranium mines.	5-3
5.2 Population statistics for humans and beef cattle	5-12
5.3 Aquatic environmental transport pathways initially considered	5-14

6.1	Annual release rates (Ci) used in the dose equivalent and health effects computations for active uranium mines	6-2
6.2	Annual release rates (Ci) used in the dose equivalent and health effects computations for inactive uranium mines	6-4
6.3	Annual working level exposure from radon-222 emissions from model uranium mines	6-6
6.4	Annual radiation dose equivalents due to atmospheric radioactive particulate and Rn-222 emissions from a model average surface uranium mine	6-7
6.5	Annual radiation dose equivalents due to atmospheric radioactive particulate and Rn-222 emissions from a model average large surface uranium mine	6-8
6.6	Annual radiation dose equivalents due to atmospheric radioactive particulate and Rn-222 emissions from a model average underground uranium mine	6-9
6.7	Annual radiation dose equivalents due to atmospheric radioactive particulate and Rn-222 emissions from a model average large underground uranium mine	6-10
6.8	Annual radiation dose equivalents due to atmospheric radioactive particulate and Rn-222 emissions from a model inactive surface uranium mine	6-11
6.9	Annual radiation dose equivalents due to atmospheric radioactive particulate and Rn-222 emissions from a model inactive underground uranium mine	6-12
6.10	Annual radiation dose equivalents due to atmospheric radioactive particulate and Rn-222 emissions from a hypothetical in situ uranium solution mine	6-13
6.11	Individual lifetime fatal cancer risk for one year of exposure and estimated additional fatal cancers to the regional population due to annual radioactive airborne emissions from model uranium mines	6-15

6.12	Individual lifetime fatal cancer risk due to lifetime exposure to radioactive airborne emissions from model uranium mines	6-16
6.13	Genetic effect risk to descendants for one year of parental exposure to atmospheric radioactive airborne emissions from model uranium mines	6-17
6.14	Genetic effect risk to descendants for a 30-year parental exposure to atmospheric radioactive airborne emissions from model uranium mines	6-18
6.15	Percent of the fatal cancer risk for the maximum individual due to the sources of radioactive emissions at model uranium mines	6-20
6.16	Percent of the fatal cancer risk for the average individual in the regional population due to the sources of radioactive emissions at model uranium mines	6-21
6.17	Percent of fatal cancer risks due to radon-222 daughter concentrations at model uranium mine sites	6-22
6.18	Percent of the fatal cancer risk for principal nuclides and pathways due to radioactive particulate and Rn-222 emissions at model uranium mines	6-23
6.19	Natural background concentrations and average urban concentrations of selected airborne pollutants in the United States	6-27
6.20	Combustion product concentrations at the site of the maximum individual with comparisons	6-29
6.21	A comparison of the airborne concentrations of nonradioactive gases at the hypothetical in situ leach site with threshold limit values	6-30
6.22	Stable trace metal airborne concentrations at the site of the maximum individual	6-32
6.23	Comparison of stable trace metal airborne concentrations at the location of the maximum individual with natural background concentrations and average urban concentrations of these airborne pollutants	6-33

6.24	Comparison of trace metal airborne concentrations at the site of the maximum individual with threshold limit values (TLV's) in the workroom environment adjusted for continuous exposure to the general public	6-34
6.25	Annual radiation dose equivalent rates due to aquatic releases from the New Mexico model underground mine	6-36
6.26	Annual radiation dose equivalent rates due to aquatic releases from the Wyoming model surface mine	6-37
6.27	Individual lifetime fatal cancer risk and committed fatal cancers to the population residing within the assessment areas	6-38
6.28	Genetic risks to succeeding generations of an individual and committed genetic effects to descendants of the present population residing within the assessment area	6-41
6.29	Comparison of nonradiological waterborne emissions from uranium mines with recommended agricultural water quality limits	6-43
6.30	Estimated lifetime risk of fatal lung cancer to individuals living in homes built on land contaminated by uranium mine wastes	6-45
6.31	Gamma radiation anomalies and causes	6-49
7.1	Distribution of United States uranium mines by type of mine and state	7-2
7.2	Sources of contaminants at uranium mines	7-3
7.3	Concentration of contaminants in waste rock (overburden), ore, and sub-ore	7-6
7.4	Summary of harm from radioactive airborne emissions of model uranium mines :	7-11
7.5	Percent additional lifetime fatal cancer risk for a lifetime exposure to the individual and the percent additional cancer deaths in the regional population per year of exposure estimated to occur as a result of uranium mining	7-12

7.6	Summary of the fatal cancer risks caused by radioactive aqueous emissions from model uranium mines	7-14
7.7	Estimated lifetime risk of fatal lung cancer to the average person living in a home built on land contaminated by uranium mine wastes	7-16
7.8	Summary of contaminant loading and stream water quality from a model surface uranium mine	7-20
7.9	Summary of contaminant loading and stream water quality from a model underground uranium mine	7-21

Appendix A

A.1	Federal laws, regulations, and guides for uranium mining	A-1
-----	--	-----

Appendix D

D.1	State laws, regulations, and guides for uranium mining	D-1
-----	--	-----

Appendix E

E.1	Active uranium mines in the United States	E-1
-----	---	-----

Appendix F

F.1	Inactive uranium mines in the United States	F-1
-----	---	-----

Appendix G

G.1	Uravan and Jamestown areas	G-14
G.2	Inactive uranium mine sites surveyed in New Mexico	G-21
G.3	Status and location of uranium mines in Texas.	G-25
G.4	Trace elements and radionuclides in water in the south fork of Box Creek drainage at UNC Morton Ranch lease	G-35
G.5	Radionuclides and trace metals in sediments in the south fork of Box Creek at UNC Morton Ranch lease	G-36
G.6	Radionuclides and trace metals in soils near the 1601 open pit mine, UNC Morton Ranch lease, Wyoming	G-37

		Page
G.7	Radionuclides and trace metals in soil profiles at the open pit mines, UNC Morton Ranch lease, Wyoming	G-38
G.8	Radionuclides and trace metals in sediments from the drainage of the San Mateo mine and from San Mateo Creek, New Mexico	G-40
G.9	Radium-226 and trace elements in water from San Mateo Creek near San Mateo mine discharge point	G-40

Appendix H

H.1	Characteristics of the sub-basin containing the model mines	H-2
H.2	Seepage and outflow calculations for the Wyoming model mine drainage system	H-6
H.3	Characteristics of the sub-basin hydrographic unit in the model underground uranium mine area	H-8
H.4	Seepage and outflow calculations for the New Mexico model mine area drainage system	H-11

Appendix J

J.1	Aquatic environmental transport pathways examined	J-6
J.2	Characteristics of the generic sites	J-20
J.3	Stream data for Valencia County	J-23
J.4	Estimation of meat production in Valencia County for 1977	J-25
J.5	Estimates of meat production in Converse County, Wyoming for 1976	J-26
J.6	Annual radionuclide release rates to streams for active uranium mines	J-29
J.7	Freshwater fish concentration factors	J-29
J.8	Normalized human intake rate factors for radionuclide uptake via plant root systems	J-31
J.9	Irrigated land usage	J-31

J.10	Soil removal rate constants and radioactive decay constants	J-33
J.11	Milk and beef concentration factors	J-33
J.12	Dose equivalent conversion factors	J-36
J.13	Health effects conversion factors for internal pathways.	J-37
J.14	Health effects conversion factors for external pathways.	J-37

Appendix K

K.1	Characteristics of the generic sites	K-1
K.2	Animal and vegetable crop distribution for use with AIRDOS-EPA	K-3
K.3	Sources of food for the maximum individual (percent)	K-4
K.4	Selected input parameters to AIRDOS-EPA	K-5
K.5	Selected terrestrial pathway parameters by radionuclide.	K-7
K.6	Effective radioactive decay constants	K-8

Appendix L

L.1	Radionuclide dose rate and health effect risk conversion factors used in uranium mine assessments	L-4
L.2	Additional input data used by DARTAB in the health impact assessment of airborne emissions	L-21
L.3	Example input data file for DARTAB	L-22
L.4	Maximum individual fatal cancer risk for one year of exposure to atmospheric radioactive emissions from model uranium mines	L-23
L.5	Fatal cancer risk to an average individual in the regional population for one year of exposure to atmospheric radioactive emissions from model uranium mines	L-24
L.6	Fatal cancer risk to the population for one year of exposure to atmospheric radioactive emissions from model uranium mines	L-25

L.7	Genetic effect risk to descendants of maximum exposed individual for one year of parental exposure to atmospheric radioactive particulate and Rn-222 emissions from model uranium mines	L-26
L.8	Genetic effect risk to descendants of average individual of the population for one year of parental exposure to atmospheric radioactive particulate and Rn-222 emissions from model uranium mines	L-27
L.9	Genetic effect risk to descendants of the regional population for one year of parental exposure to atmospheric radioactive particulates and Rn-222 emissions from model uranium mines	L-28

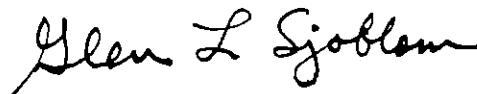
FOREWORD

The Uranium Mill Tailings Radiation Control Act of 1978 stipulates that "...the Administrator, in consultation with the Commission, shall provide to the Congress a report which identifies the location and potential health, safety, and environmental hazards of uranium mine wastes together with recommendations, if any, for a program to eliminate these hazards." It is our understanding that the intent of Congress was to determine if remedial actions similar to those for uranium mill tailings are required for mine wastes.

The report was prepared by the Office of Radiation Programs and addresses potential health effects caused by air emissions, water effluents, and solid wastes at active and inactive uranium mines. It is probably the single most comprehensive report on the subject. The effects from other mining activities such as exploration, site preparation, and in situ leaching were evaluated in proportion to their potential significance and the amount of available information about them. Comments on this report from the uranium mining industry, States, and the Nuclear Regulatory Commission have also been considered.

The conclusions and recommendations are in the Executive Summary and Chapter 7 of the report. The principal findings of this report are as follows:

1. No problems were identified that require Congressional action.
2. Standards are probably needed to control human exposure from radioactive emissions from underground uranium mines. We have proposed a standard for underground uranium mines under the Clean Air Act program to develop radionuclide standards.
3. Regulations should be considered for maintaining the control of solid wastes at active uranium mines to prevent off-site use and to minimize the health risks from these materials. This is part of the overall agency consideration of mining wastes and is being carried out under the auspices of the Solid Waste Disposal Act.
4. The report also identifies additional studies that are needed to completely elucidate the potential for local adverse effects as a result of possible misuse of the mine waste materials in construction of buildings. Preliminary reports of field studies by EPA identifying possible sites at which mine wastes may have been utilized in construction or around buildings have been sent to the States for follow-up studies.



Glen L. Sjoblom, Director
Office of Radiation Programs

ACKNOWLEDGEMENTS

The following persons of the Office of Radiation Programs made substantial contributions to this report.

R. L. Blanchard, EERF, Montgomery, AL*

G. G. Eadie, ORP-Las Vegas, NV*	P. J. Magno, CSD, Washington, DC
T. W. Fowler, EERF, Montgomery, AL	J. M. Moore, ORP-Las Vegas, NV
M. M. Gottlieb, TAD, Washington, DC	D. Nelson, CSD, Washington, DC
J. M. Hans, Jr., ORP-Las Vegas, NV*	M. F. O'Connell, ORP-Las Vegas, NV
T. R. Horton, EERF, Montgomery, AL	C. M. Petko, EERF, Montgomery, AL
T. L. Hurst, ORP-Las Vegas, NV	J. E. Regnier, CSD, Washington, DC
R. F. Kaufmann, ORP-Las Vegas, NV*	J. S. Silhanek, CSD, Washington, DC
	J. M. Smith, EERF, Montgomery, AL

* Principal Authors

The following persons provided data and information used in this report:

L. V. Beal, U.S. Geological Survey, Albuquerque, NM
R. Beckman, U.S. Dept. of Labor, Denver, CO
J. D. Borland, U.S. Geological Survey, Albuquerque, NM
T. Buehl, New Mexico Environmental Protection Agency, Santa Fe, NM
T. Bullock, Utah Industrial Commission, Salt Lake City, UT
A. J. Carroll, U.S. Dept. of Interior, Denver, CO
T. Chung, U.S. Dept. of Energy, Grand Junction, CO
L. M. Cook, Texas Dept. of Health, Austin, TX
J. T. Dale, USEPA, Region VIII, Denver, CO
J. G. Dudley, NM Environmental Improvement Div., Santa Fe, NM
W. H. Engelmann, U.S. Bureau of Mines, Twin Cities, MI
J. R. Giedt, USEPA, Region VIII, Denver, CO
A. L. Hornbaker, Colorado Geological Survey, Denver, CO
S. J. Hubbard, IERL, USEPA, Cincinnati, OH
R. G. Kirby, USEPA, Effluent Guidelines Division, Washington, DC

J. L. Kunkler, U.S. Geological Survey, Santa Fe, NM
H. W. Lowham, U.S. Geological Survey, Cheyenne, WY
H. D. May, USEPA, Region VI, Dallas, TX
R. Meehan, U.S. Dept. of Energy, Grand Junction, CO
A. T. Mullins, TVA, Chattanooga, TN
G. E. Niewiadomski, U.S. Geological Survey, Washington, DC
B. L. Perkins, New Mexico Energy and Minerals Department, Santa Fe, NM
C. R. Phillips, USEPA, EERF, Montgomery, AL
H. G. Plimpton, MSHA, Salt Lake City, UT
T. J. Price, Bendix Field Engineering Corp., Grand Junction, CO
J. G. Rankl, U.S. Geological Survey, Cheyenne, WY
R. F. Reed, U.S. Bureau of Mines, Washington, DC
G. C. Ritter, Bendix Field Engineering Corp., Grand Junction, CO
P. B. Smith, USEPA, Region VIII, Denver, CO
J. P. Stone, U.S. Dept. of Interior, Washington, DC
A. B. Tanner, U.S. Geological Survey, Reston, VA
S. Waligora, Eberline Inst. Co., Albuquerque, NM
R. E. Walline, USEPA, Region VIII, Denver, CO
T. Willingham, USEPA, Region VIII, Denver, CO
T. Wolff, New Mexico Environmental Protection Agency, Santa Fe, NM
A. F. Wright, (formerly) U.S. Geological Survey, Albuquerque, NM

The authors express their appreciation to Mrs. Winnifred Schupp, ORP-Las Vegas, NV, and Mrs. Annette Fannin, EERF, Montgomery, AL, for typing the report and to Mrs. Edith Boyd, ORP-Las Vegas, NV, for preliminary editing of the report.